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Recent Observations of Electron Intensities in the Earth's Outer Magnetosphere and Beyond*

by

L. A. Frank,** J. W. Freeman, Jr.,** and J. A. Van Allen

Department of Physics and Astronomy
State University of Iowa
Iowa City, Iowa

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ABSTRACT

A comprehensive study of the distribution of low energy electrons in the outer portions of the earth's magnetosphere, in and near the geomagnetic equatorial plane, is being made by means of zero-wall-thickness CdS total energy flux detectors and thin-windowed (1.2 mg/cm^2 mica) Geiger-Mueller tubes on the long life-time satellites Explorers XII and XIV, whose geocentric apogee distances are 83,000 km and 105,000 km, respectively. Observations are now available within the outer magnetosphere, at its boundary and beyond; and over a wide range of sun-earth-probe angles from positions on the noon meridian to ones on the midnight meridian. Results of the electron intensity measurements reported herein are concerned with:

(a) The nature of the interface between the region dominated by the geomagnetic field and the region of the interplanetary medium;

(b) Evidence for a "piston" of quasi-thermalized solar plasma, consisting predominantly of 1 to 10 keV electrons, on the sunward side of the magnetospheric boundary and having a radial thickness of some 10,000 km;

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(c) A comprehensive mapping of the omnidirectional intensity of electrons of energy $\geq$ 40 keV, showing that, near the geomagnetic equatorial plane, the magnetospheric boundary occurs typically at about 10 earth radii at the sub-solar point and has an approximately circular form to a sun-earth-probe angle of about 70°, then "flares out" to an ogival shape with a radial distance of some 16 earth radii on the dawn meridian; and

(d) The discovery of a relative "void" of electrons of energy $\gtrsim$ 40 keV on the night side of the earth in a region bounded on its earthward side by the "classical" region of trapped, outer zone electrons at 7 earth radii and on its outward side by the ogival skirt of much higher intensities.

These observations provide a new foundation for the formulation of physical models of the earth's magnetosphere and of the interaction of the solar wind with the geomagnetic field and give a significant measure of coherence to a diverse body of previously discordant observations.

INTRODUCTION

Several earth satellites and space probes have been used to study the intensity of charged particles in the outer portions of the earth's magnetosphere beyond 40,000 kilometers. (See, for example, Pioneers III and IV [Van Allen and Frank, 1959 a, b], Explorer VI [Hoffman, Arnoldy, and Winckler, 1962], Explorer XII [Rosser, O'Brien, Van Allen, Frank, and Laughlin, 1962], Explorer X [Bridge, Dilworth, Lazarus, Lyon, Rossi, and Scherb, 1962], Lunik II [Gringauz, Kurt, Moroz, and Shklovskii, 1961], and Explorer XIV [Frank, Van Allen, and Macagno, 1963].) These measurements together with simultaneous measurements of the magnetic field (for reviews, see Smith [1963] and Sonett [1963]; Explorer X [Heppner, Ness, Scearce, and Skillman, 1963]; Explorer XII [Cahill and Amazeen, 1962] [Freeman, Van Allen, and Cahill, 1963]) have contributed to the rapidly-developing body of knowledge of the physical phenomena of the earth's outer magnetosphere and of the interaction of the solar wind with the geomagnetic field. Of particular interest are the shape of the magnetospheric boundary and the distribution of energetic charged particles and of plasma in its vicinity. It seems probable that the generation of the energetic particles which produce aurorae and enhanced atmospheric heating and ionospheric absorption at high latitudes is associated with the magnetospheric boundary [cf., Van Allen, McIlwain, and Ludwig, 1959; O'Brien, 1963].

OBSERVATIONS WITH EXPLORER XII AND EXPLORER XIV

In the following we review some of the principal experimental results obtained by low-energy charged particle detectors on Explorers XII and XIV, which have recently monitored the particle intensities near the geomagnetic equatorial plane at large geocentric radial distances, from local noon to local midnight on the westward side of the earth-to-sun line.

In Figure 1 are shown the areas in the geomagnetic equatorial region surveyed by Explorers XII and XIV with reference to the earth-to-sun line and as seen looking downward at the north geomagnetic pole. It is noted that a quite complete spatial survey extending to some 84,000 kilometers radial distance in the case of Explorer XII and to 105,000 kilometers for Explorer XIV has been obtained. Further salient properties of these orbits are summarized in Table I.

We first turn our attention to some of the recent charged particle measurements obtained with Explorer XII. Table II gives the significant properties of the charged particle detectors employed in the following discussion. The CdS crystal energy flux detector, CdSTE, is sensitive to energy fluxes exceeding 1 erg $(cm^2 \text{ sec ster})^{-1}$ consisting of electrons of energy $E \geq 200$ eV or protons of energy $E \geq 1$ MeV or heavy ions of similar energy. The SpL and SpH detectors are "low" and "high"

Table I

Orbital Parameters for Explorers XII and XIV

	Explorer XII	Explorer XIV
Launch Date	August 16, 1961	October 2, 1962
Termination of Data Transmission	December 6, 1961	Still operating on May 28, 1963
Geocentric Apogee Distance	83,600 km	104,900 km
Geocentric Perigee Distance	6,700 km	6,700 km
Orbital Inclination	33°	33°
Anomalistic Period	26.5 hours	36.4 hours
Satellite Spin Rate	30 rpm	9.6 rpm

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Table II

S.U.I. Detector Characteristics on Explorer XII

Detector	Symbol	Solid Angle (Steradians)	Geometric Factor	Directly Detectable Particles through the Quoted Solid Angles
Anton 302 GM Tube	302	4π	$0.75\ cm^2$	Electrons $E \geq 1.6$ MeV Protons $E \geq 20$ MeV
Electron Spectrometer Channels	SpL SpH	--- ---	$10^{-5}\ cm^2$ ster	Electrons 40 keV $\leq E \leq$ 50 keV Electrons 80 keV $\leq E \leq$ 100 keV
CdS Total Energy Flux Detector	CdSTE	10^{-2}	3×10^{-4}	Electrons 200 eV $\leq E \leq$ 500 keV, Protons 1 keV $\leq E \leq$ 10 MeV, Light
CdS Proton Energy Detector	CdSB	10^{-2}	3×10^{-4}	Protons 1 keV $\leq E \leq$ 10 MeV, Light
CdS Optical Monitor	CdSOM	10^{-2}	3×10^{-4}	Light

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energy channels of an electron spectrometer employing permanent magnets for angular dispersion of the electrons and two thin window Geiger tubes as detectors. The rates of these detectors is corrected for background penetrating radiation by the rate of an identical tube with the same omnidirectional shielding but with no aperture. A more thoroughgoing discussion of the S.U.I. Explorer XII instrumentation is given in Rosser et al. [1962].

As an exemplary case of the Explorer XII data when the satellite enters the magnetosphere within a few degrees of the sub-solar point (local noon), we shall discuss the inbound pass on the 13th of September, 1961 [Freeman, Van Allen, and Cahill, 1963].

No flares of importance greater than 1^+ were reported for the three days prior to September 13, although there were six class 1 flares and one 1^+ flare on the 10th of September. At 15h 56m U.T. on September 13, there occurred a geomagnetic sudden commencement which resulted in a K_s index of 4 at Wingst and Gottingen. The K_p index remained at or below 4 until 24 hours later, at which time it rose to 6. As shown in Figure 2, the magnitude of the sudden commencement at San Juan was 10 to 25 gammas in the horizontal component. The positive phase continued for over two days. Both the Fort Churchill and Meanook magnetograms show very little magnetic activity on the 13th of September.

In contrast to these comparatively mild indications of solar activity and of perturbations of the geomagnetic field at the surface of the earth, there was found to be a high level of disturbance in magnetic and particle phenomena at the boundary of the magnetosphere. In Figure 3 are displayed the counting rates of the five S.U.I. particle detectors and the magnetic field measurements as a function of geocentric radial distance on the inbound pass of September 13, 1961. The following features are noteworthy:

1. The output of the CdS total energy flux detector (CdSTE) steadily increased as the satellite moved inward from apogee. There was an apparently significant drop in flux more or less coincident with the s.c. as reported on the earth. The maximum value of the spin-averaged energy flux, 50 ergs $(cm^2 \text{ sec sterad})^{-1}$, occurred at 55,000 km. Thereafter the measured flux diminished rapidly in the vicinity of the interface but increased again within the trapping region.

2. The low energy ($40 \leq E \leq 50$ keV) channel of the electron spectrometer (SpL) showed no increase of counting rate above that due to galactic cosmic rays until about 52,000 km. In Figure 3 the counting rates of both low energy (SpL) and high energy ($80 \leq E \leq 100$ keV) (SpH) spectrometer channels have been corrected for non-collimated particles by subtracting the rates of the background detector, SpB.

At 52,000 km the counting rates began to rise sharply and reached their peaks at 45,000 km.

3. The onboard magnetometer data (courtesy of L. J. Cahill) shown in the center frame of Figure 3 indicates that at 52,000 km the satellite entered the region where the magnetic field was regular and had a magnitude and direction approximately those for a dipole field.

It has been proposed by Cahill [1962] that the magnetic field measurements give direct evidence for the compression of the geomagnetic field under the impact of solar plasma and that the discontinuity in magnetic parameters at 8.2 earth radii (at the sub-solar point) defines the physical boundary between the inner region in which the magnetic field energy density is dominant and the outer region in which the plasma energy density is dominant. We consider that the particle measurements support this interpretation in the following manner:

1. The sharp rise in counting rates of the 302 and of both the spectrometer channels at 8.2 earth radii gives evidence that durable geomagnetic trapping of charged particles is possible at lesser radii but is impossible at greater radii due to the disordered nature of the field at greater radii.

2. The peak in intensity of 50 keV electrons inside the boundary may arise from acceleration mechanisms associated with a transient compression and agitation of the geomagnetic field in which they are trapped.

3. The CdS total energy flux detector shows the presence of large fluxes of low-energy charged particles in the region of disordered field outside the interface. It has been argued [Freeman et al., 1963] that the detailed consideration of the responses of the companion charged particle detectors on Explorer XII show that the particles being measured are very likely electrons of energy 1 keV $\leq$ E $\leq$ 10 keV with omni-directional intensities of the order of 10^{10} $(cm^2\ sec)^{-1}$. We propose that they constitute the observable component of a quasi-thermalized solar plasma.

There are forty passes during the active life of Explorer XII for which light and telemetry conditions are such that the CdS detectors provide a monitor of the energy flux outside the magnetosphere on the sunward side of the earth. In each of the forty cases the CdSTE detector indicates the presence of an energy flux above the threshold for the detector (approximately 1 erg $(cm^2\ sec\ ster)^{-1}$). If, as we have proposed, this energy flux results from the electron component of the thermalized solar plasma we should expect to observe a correlation between the intensity of this energy flux and some other parameter representative of the solar plasma pressure. Such a parameter is the radial position of the magnetospheric boundary as determined by the termination of the geomagnetically trapped radiation. Specifically one would expect to see the highest

CdSTE external fluxes during passes when the magnetospheric boundary is closest to the earth. In Figure 4 the maximum CdSTE counting rate external to the boundary of each of the forty passes has been plotted as a function of the observed boundary position for the same pass. There is some evidence for the belief that higher plasma fluxes are associated with boundary positions closer to the earth. This correlation for cases of abrupt termination of the outer boundary of the plasma flux region (solid circles in Figure 4) is better than for cases of when the termination is gradual (open circles in Figure 4).

Figure 5 is an example of a pass on which an abrupt termination of the (non-trapped) plasma flux region was observed. The median value of the distance from the magnetospheric boundary to the position of the discontinuity for 13 such passes is approximately 12,000 km. We suggest that this value may represent the stand-off distance of the shock front produced by the supersonic flow of solar plasma past the magnetosphere, as discussed by Kellogg [1962]. Our observed values for this quantity are in rough agreement with the prior theoretical estimates.

In Figure 6 is summarized the geocentric radial position of the magnetospheric boundary, defined by the radial termination of trapped 50 keV electrons, as a function of time for the first two and a half months of the Explorer XII lifetime. These are also shown with the corresponding D_{st} (H) values from San Juan and Honolulu magnetograms. The following features are noted:

1. The average boundary position on the sunward side of the earth is 66,000 km out to a geocentric sun-earth-probe angle of 70°.

2. Positive, or above normal, D_{st} values are associated with closer-than-average boundary positions, the maximum inward excursion being about 15,000 km inside the average boundary position.

3. A closer-than-average boundary position during the initial phase appears to persist throughout the main phase.

4. The recovery phase of magnetic storms is associated with an outward motion of the boundary, the radial extent of this motion exceeding Explorer XII's apogee, 83,500 km, for large storms such as those which occurred on 1 October and 28 October 1961.

From the above observations we conclude that the gross features of the boundary motion have their surface equatorial field counterparts as was suggested originally by Chapman and Ferraro [1933]--the initial phase resulting from the compression of the magnetosphere by the enhanced solar plasma flow, and the recovery phase outward-boundary-motion resulting from the relief of solar plasma pressure against the boundary of the compressed magnetosphere.

The extension of the charged particle measurements in the outer magnetosphere to the night side of the earth was accomplished by Explorer XIV, which was launched on 2 October 1963 into an orbit whose apogee of 105,000 km radial distance from the center of the earth was directed at a sun-earth-probe angle of 71° at launch. The characteristics of our charged particle detectors on Explorer XIV are summarized in Table III. A more complete discussion of the payload and experimental apparatus is given by Frank, Van Allen, Whelpley, and Craven [1963]. The details of the data analyses are given by Frank, Van Allen, and Macagno [1963]. Several important factors in this analysis are:

1. We are considering the electron intensities measured with the 213A detector (a collimated Anton G.M. tube with a 1.2 mg/cm^2 mica window) for radial distances of 40,000 to 105,000 km.

2. The outputs of the other three detectors established that 213A was measuring essentially a pure electron beam ($E \geq 40$ keV) whose integral number-energy spectrum fell off by at least one order of magnitude between 40 and 200 keV.

3. The geomagnetic latitude associated with the data used here was 15° or less unless specified otherwise.

Figures 7 and 8 show two comprehensive runs of data obtained on inward passes of Explorer XIV in early October 1962.

Table III

Characteristics of SUI Detectors on Explorer XIV

	Omnidirectional			Directional		
Detector (Anton Type)	Shielding	Penetrating Particles	Geometric Factor (cm^2)	Shielding	Penetrating Particles	Geometric Factor (cm^2 ster)
213A	Side Shielding: 4.4 gm/cm^2 Pb and 0.55 gm/cm^2 Mg	Protons $\geq$ 70 MeV Electrons $\geq$ 10 MeV	0.2	1.2 mg/cm^2 mica	Protons $\geq$ 500 keV Electrons $\geq$ 40 keV	2×10^{-3}
213B	Side Shielding: 4.4 gm/cm^2 Pb and 0.55 gm/cm^2 Mg	Protons $\geq$ 70 MeV Electrons $\geq$ 10 MeV	0.2	48 mg/cm^2 Al	Protons $\geq$ 4.5 MeV Electrons $\geq$ 230 keV	2×10^{-3} (6×10^{-4} for outer zone electron spectrum*)
213C	Side Shielding: 4.4 gm/cm^2 Pb and 0.55 gm/cm^2 Mg	Protons $\geq$ 70 MeV Electrons $\geq$ 10 MeV	0.2	1.2 mg/cm^2 mica plus sweeping magnet	Protons $\geq$ 500 keV Electrons $\geq$ 200 keV	3×10^{-3}
302	265 mg/cm^2 Mg and 400 mg/cm^2 Stainless Steel	Protons $\geq$ 23 MeV Electrons $\geq$ 1.6 MeV	0.6 (0.1 for outer zone electron spectrum*)	--	--	--

* See Frank, Van Allen, Whelpley, and Craven [1963] for details.

The effective boundary of the magnetosphere was characterized by the precipitous increase of counting rate of 213A at approximately 70,000 km and at a sun-earth-probe angle L_{SEP} of 65°. The omnidirectional intensity of electrons of energy greater than 40 keV, J_o ($\geq$ 40 keV), at 75,000 km was less than 5×10^2 $(cm^2\ sec)^{-1}$, at 60,000 km was 5×10^6 $(cm^2\ sec)^{-1}$, and at 50,000 km was 5×10^7 $(cm^2\ sec)^{-1}$.

Figures 7 and 8 also exhibit the "roughness" of the structure of the outer magnetosphere (spatial and temporal variation) which was characteristic of the entire body of data. Such roughness is in itself a corollary to the main thread of interpretation in later sections. Meanwhile, the central objective of the analysis is to establish the gross spatial structure of the low energy electron distribution during October, November, and December 1962, during which period the apogee of the orbit of Explorer XIV moved westward toward the night side of the earth.

Figure 9 shows the 213A data on the pass (greater L_{SEP} than the companion inward pass in Figure 7) on October 4. It is noted immediately that:

1. The omnidirectional intensity remained at a value of order 10^6 $(cm^2\ sec)^{-1}$ out to at least 100,000 km radial distance; and

2. The variations of counting rate beyond 60,000 km were markedly greater than on the inward pass at lower L_{SEP}.

It may be remarked that the graphs exhibited here are representative members of classes of such graphs obtained under the successive regimes cited above.

Figure 10 shows data for a representative outward pass at a later date (November 22) and larger L_{SEP}. Note that:

1. Electron intensities of order 2×10^6 $(cm^2\ sec)^{-1}$ existed in the range 70,000 to 100,000 km <u>but</u>

2. A much lower intensity of electrons, about 2×10^4 $(cm^2\ sec)^{-1}$, occurred in the range 40,000 to 70,000 km and

3. A rapid decline in intensity was found at 33,000 km.

It was readily apparent from the data which have been illustrated in the foregoing paragraphs and Figures 7, 8, 9, and 10 that there was a marked departure from rotational symmetry about the magnetic axis of the earth in the distribution of energetic electrons. Hence we have found it convenient and informative to summarize the data for twenty complete orbits of Explorer XIV during the time period under discussion by constructing a diagram of contours of specified omnidirectional intensity of electrons of energy greater than 40 keV in the geomagnetic equatorial plane. The result is shown in Figure 11.

Explorer XII data /Rosser et al., 1962/ have been used to fill in the contours for values of L_{SEP} less than 60°. The contours are smoothed curves connecting points of approximately equal omnidirectional intensity on twenty diagrams such as shown in Figures 7, 8, 9, and 10 (plus similar diagrams of Explorer XII data as just noted). Since there are substantial time variations of electron intensity in the outer magnetosphere at fixed values of L_{SEP} and R_E, Figure 11 cannot be taken to represent accurately the full situation at a given instant. The diagram does portray faithfully the major features of the time-averaged structure function of electrons having $E \geq 40$ keV. The following explicit remarks refer to the limitations of Figure 11:

1. The regions of rapid temporal (~ day) and spatial variations are darkened in Figure 11.

2. Explorers XII and XIV measurements used in the construction of the diagram were made only to the west of the earth-sun line. Symmetry about this line has been assumed to obtain the contours to the east of the earth-sun line in the geomagnetic equatorial plane. (This aspect is now being examined with new data from Explorer XIV to the east of the earth-sun line but the results have not been analyzed at the date of writing.)

3. Changes in the shape of the outer boundary of the magnetosphere during marked geomagnetic activity such as that of October 24-26 /preliminary reports of solar activity by

Billings, Trotter, and LaVelle, High Altitude Observatory, Boulder, Colorado/ have not yet been studied using Explorer XIV data. Therefore during such periods the validity of Figure 10 is unknown.

4. Occasionally, large spikes of intensity ($\geq 10^6$ $(cm^2\ sec)^{-1}$) appear at the earthward side of the boundary of the void (40,000 to 50,000 km).

5. At the present time we are not able to determine whether or not the observed electrons in the outer skirt of the diagram are trapped, due to lack of knowledge of their angular distributions and of the geomagnetic field in these regions.

6. Due to the fact that the radial extent of the populated region exceeds the apogee distance (105,000 km) of the satellite for $L_{SEP} \sim 90°$, the nature of the flux contours beyond 16 R_E cannot be determined. Detailed study of further data may yield an indication of the shape of the contours beyond 105,500 km. This is now being investigated.

DISCUSSION OF RELATED, PREVIOUS WORK

It is of interest to compare our new experimental results as summarized in Figure 11 with those obtained by previous satellites and space probes. It is found that a significant level of coherence is introduced into a previously rather bewildering situation, viz.:

1. Pioneer III (December 6-7, 1958).

On the outward pass at 61,400 km L_{SEP} was 40°; at apogee at 108,700 km, 18°; on the inward pass at 60,300 km, 11°, all three angles lying to the westward of the earth-to-sun line. The counting rate of the 302 detector on Pioneer III as a function of radial distance [Van Allen and Frank, 1959b] was similar to that of an identical 302 on Explorer XIV in early October (Figure 1) at $L_{SEP} < 70°$.

2. Pioneer IV (March 3, 1959).

At 59,700 km, L_{SEP} was 65° and at 101,700 km it was 56°, both angles being west of the earth-to-sun line. During the several days prior to the flight of Pioneer IV [Van Allen and Frank, 1959a], substantial solar-geomagnetic activity occurred which, when coupled with the larger L_{SEP} of the spacecraft relative to that of Pioneer III and thus the closer proximity to the "flaring" (large increase in radial extent for small increases of L_{SEP}) of the contours in Figure 11, may account for the marked radial extension of the Pioneer IV 302 counting rate contour as compared to that of an identical detector on Pioneer III.

3. Lunik II (September 12, 1959).

L_{SEP} for Lunik II in the radial distance range 60,000 to 85,000 km has been estimated by several American authors [Freeman, Van Allen, and Cahill, 1963] [Smith, 1963] to have been 125° (± 10°) east of the earth-to-sun line. Detectable response above background terminated at approximately 85,000 km (13 earth radii) [Vernov, Chudakov, Valukov, Logachev, and Nikolaev, 1961] for a Geiger-Mueller tube shielded considerably more heavily (180 mg/cm^2 copper) than the 213 A tube (1.2 mg/cm^2 mica) on Explorer XIV. Using ion trap data from the same flight, Gringauz et al. [1961] reported the existence of a "third radiation belt" consisting of electrons of E ≥ 200 eV, in the region 61,400 to 81,400 km. Our Explorer XIV data from 213 A at an L_{SEP} of about 125° west of the earth-to-sun line (Figure 10) on November 22, 1962 were strikingly reminiscent of the observations of Gringauz et al. and thus serve to place the latter in better perspective.

4. Explorer X (March 25-28, 1961).

By means of a plasma probe [Bridge, Dilworth, Lazarus, Lyon, Rossi, and Scherb, 1962] and a magnetometer [Heppner, Ness, Scearce, and Skillman, 1963] on Explorer X, it was found that the apparent boundary of the magnetosphere occurred at $L_{SEP} \sim 145°$ southeast of the earth-to-sun line at a radial distance of the order of 135,000 km. This result appears to be generally concordant with our Figure 11 if it be supposed that the diverse instruments on Explorer XIV and Explorer X all serve the gross function of defining the magnetospheric boundary, irrespective of their more detailed properties.

5. Explorer VI (August-October 1959).

On August 16, 1959, some nine days after launch, Explorer VI attained an L_{SEP} of 125° east at the apogee position of 48,000 km [Arnoldy, Hoffman, and Winckler, 1960]. Hence Explorer VI at apogee was in the "void" as measured by Explorer XIV on the night side of the earth. Indeed Hoffman, Arnoldy, and Winckler [1962] found the outer boundary of the trapping region (with a 302 detector) to be at about 45,000 km in the geomagnetic equatorial plane. Again it appears that our Figure 11 serves to reconcile the long-standing discrepancy in the value of the outer limit of the trapping region as measured with Pioneer III, Pioneer IV, and Explorer XII (~ 65,000 km) with the much lower value (~ 45,000 km) measured by the Minnesota group with a similar detector in Explorer VI.

6. Explorer XII (August-December 1961).

The corresponding data from Explorer XII have been discussed previously and have been utilized in the construction of Figure 11.

7. Injun I (June 1961--January 1963).

It is seen in Figure 11 that the inner portion of the diagram extends to about 10 earth radii on the noon meridian but only to about 7 earth radii on the midnight meridian. This feature of the diagram may contribute to the understanding of the diurnal variation of the high latitude boundary of the trapping region as reported by O'Brien [1963] on the basis of Injun I data at 1000 km altitude. He found that the high latitude boundary of trapped electrons occurred at a latitude of about 6° farther north (in the Northern Hemisphere) during the day than it did during the night. It is difficult to make a conclusive interpretation of this result in the frame of reference of the new Explorer XII - Explorer XIV picture due to lack of definitive knowledge of the configuration of the magnetic field. Nonetheless, the Injun I result is seen to be qualitatively concordant with Figure 11.

It is abundantly clear that a great diversity of physical phenomena is associated with the interface between the magnetosphere and the interplanetary solar wind. The present observations support the view that auroral phenomena have their origin in the region $70° \leq L_{SEP} \leq 120°$ at a radial distance of some 8 to 15 earth radii [cf., Alfven, 1950] [Akasofu and Chapman, 1961].

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FIGURE CAPTIONS

Figure 1. The areas of the geomagnetic equatorial plane surveyed by Explorers XII and XIV as seen looking down along the north geomagnetic pole. Explorer XIV is still transmitting data (May 25, 1963).

Figure 2. The San Juan magnetogram for September 13-14, 1961 showing the sudden commencement at 15h 56m U.T. on September 13 and the mild, prolonged "initial" phase.

Figure 3. Particle and magnetic field measurements with Explorer XII for the inbound pass on September 13, 1961. The CdSB detector counting rate has been normalized to the energy scale of the CdSTE detector. The counting rates of both CdS detectors are very nearly linear with energy flux. Both the spectrometer high (SpH) and low energy (SpL) channel counting rates have been corrected for background counts by the subtraction of the counting rate of the background detector, SpB. The CdS optical monitor (not shown) indicated that during this pass the CdS detectors did not have any bright objects within their field of view. $|F|$ denotes the scalar magnetic field strength; α the angle between the F-vector and the spin-axis of the satellite; and ψ the dihedral angle between the plane containing the F-vector and the spin axis and the plane containing the spin axis and the satellite-sun line [cf. Cahill and Amazeen, 1962].

FIGURE CAPTIONS (continued)

Figure 4. Maximum CdSTE counting rate external to the magnetospheric boundary for forty passes of Explorer XII as a function of the observed boundary position for the same pass.

Figure 5. Exemplary pass during which an abrupt termination of the (non-trapped) plasma flux region was measured by Explorer XII.

Figure 6. A graphical summary of the geocentric radial position of the magnetospheric boundary, as defined by the radial termination of trapped 50 keV electrons, as a function of time for the first two and a half months of Explorer XII lifetime.

Figure 7. Typical G.M. detector counting rates for an inward pass of Explorer XIV during early October. At 72,000 km, L_{SEP} was 58° and λ_m was less than 15° beyond 20,000 km.

Figure 8. Inward pass on October 6-7 similar to that of Figure 1.

Figure 9. The outward pass preceding the inward pass of Figure 1. The geomagnetic latitude λ_m was approximately 20° and at 100,000 km L_{SEP} was 70°.

Figure 10. The 213A counting rate curve for the outward pass on November 22. There was a striking sparcity of electrons between 40,000 and 70,000 km ($\lambda_m \sim 15°$).

Figure 11. Summary of observed omnidirectional intensities of electrons ($E \gtrsim 40$ keV) obtained from approximately twenty complete orbits of Explorer XIV during October-December 1962 and from Explorer XII during August-December 1961. (See text.)

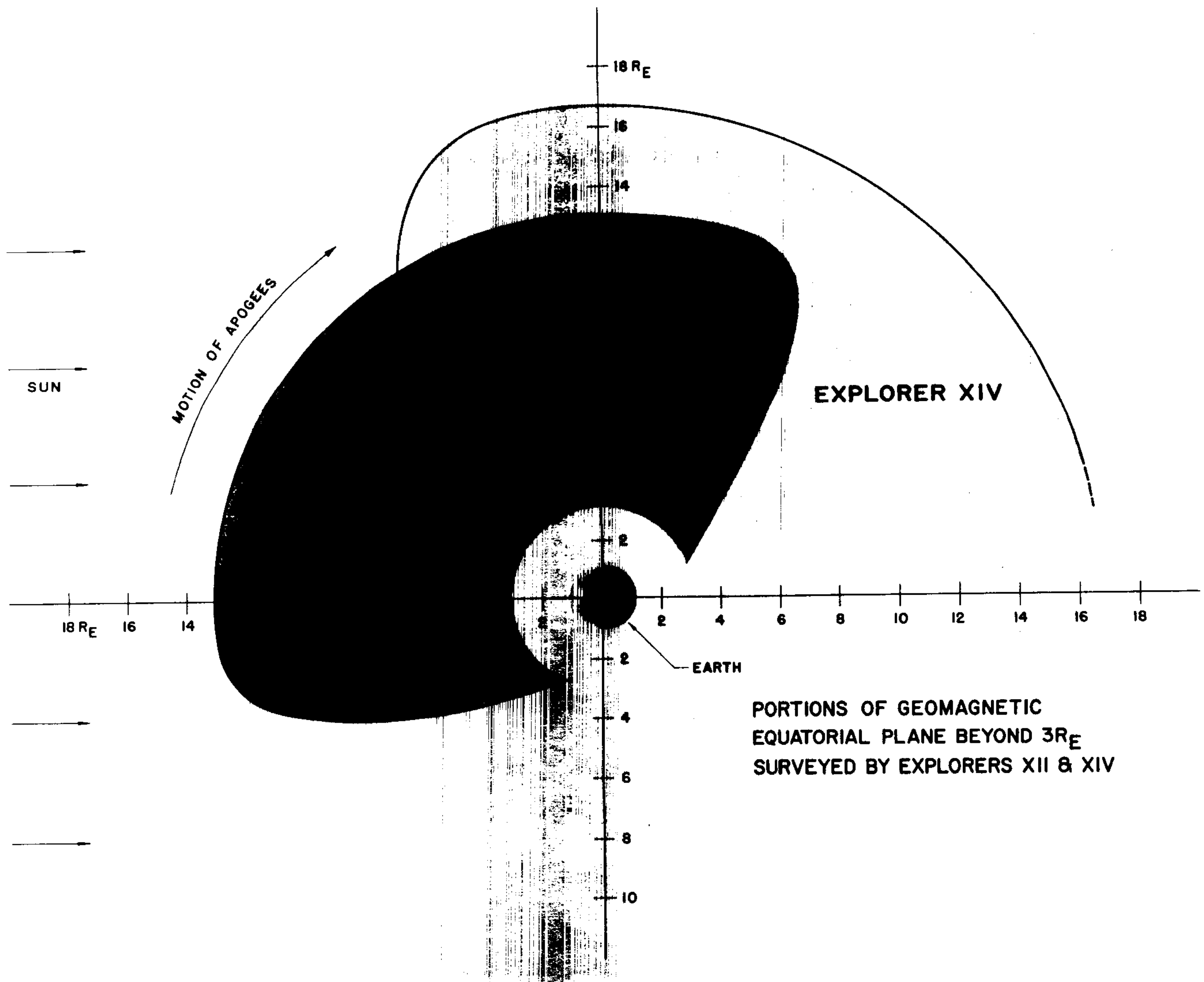

18 R_E
16
14
2
4
6
8
10
12
18
EXPLORER XIV
MOTION OF APOGEES
SUN
18 R_E
EARTH
PORTIONS OF GEOMAGNETIC
EQUATORIAL PLANE BEYOND $3R_E$
SURVEYED BY EXPLORERS XII & XIV

Figure 1

#62-539

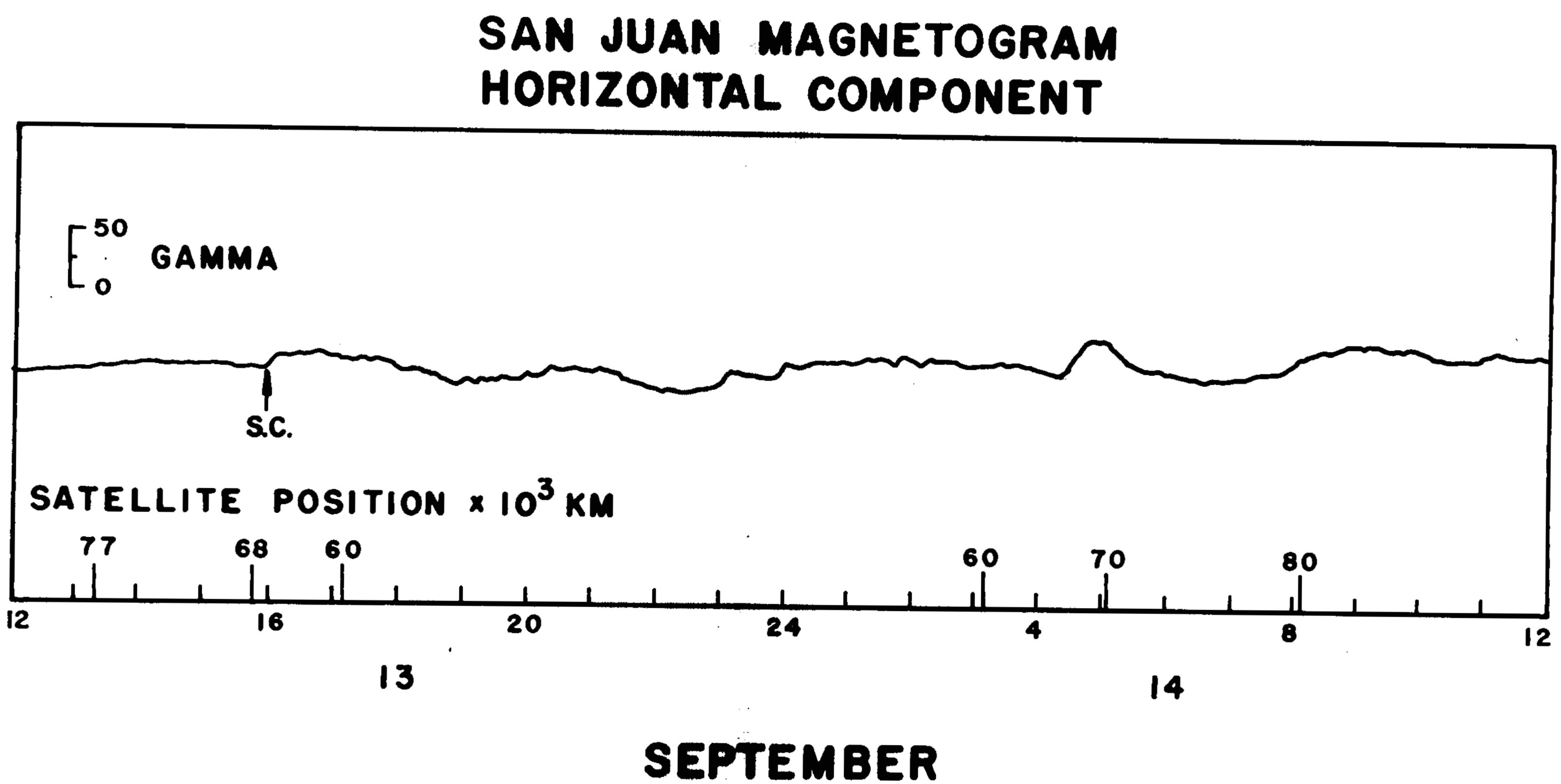
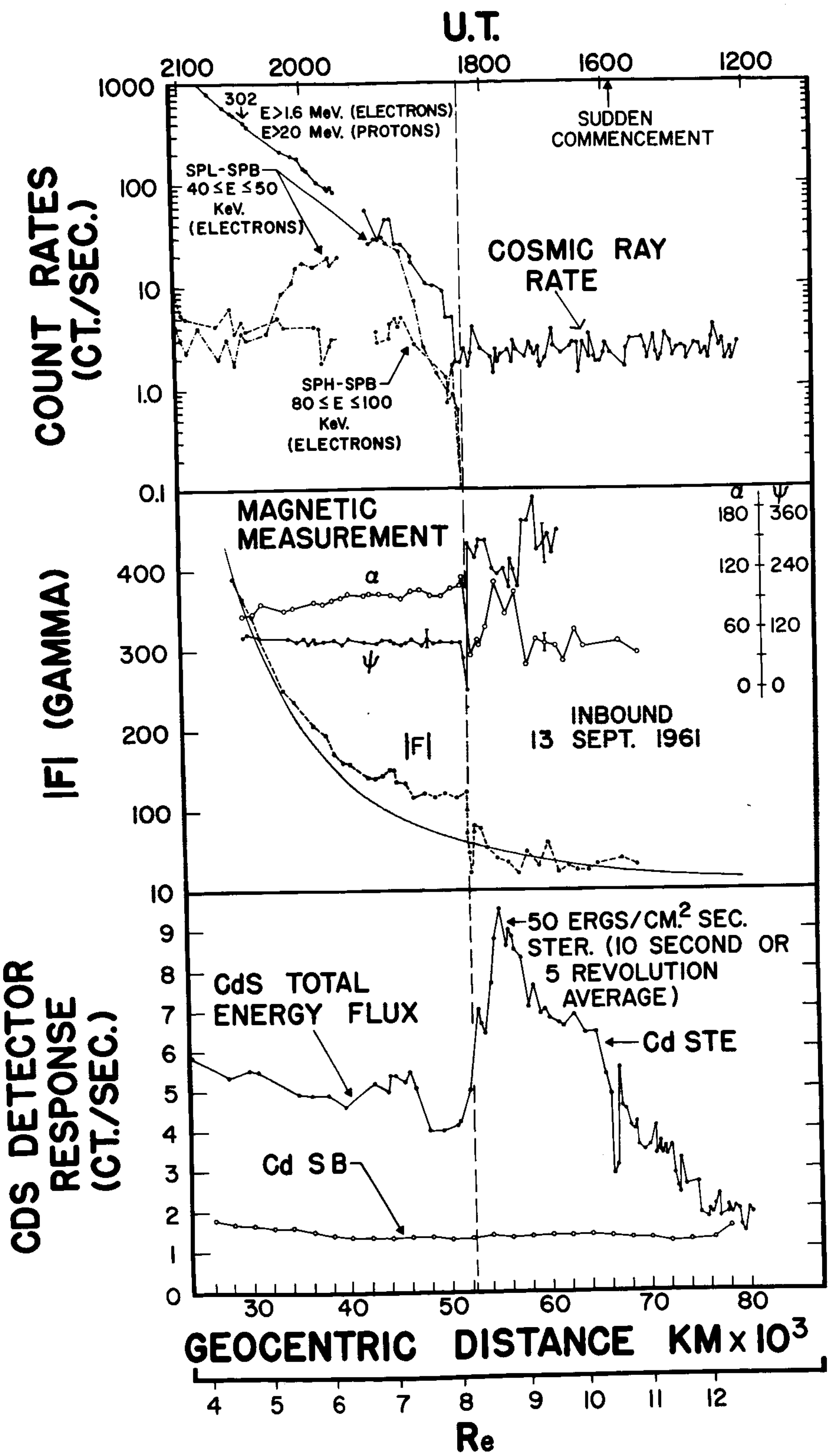


Figure 2



U.T.
2100
2000
1800
1600
1200
1000
100
10
1.0
0.1
302
E>1.6 MeV. (ELECTRONS)
E>20 MeV. (PROTONS)
SUDDEN
COMMENCEMENT
SPL-SPB
40 ≤ E ≤ 50
KeV.
(ELECTRONS)
COSMIC RAY
RATE
SPH-SPB
80 ≤ E ≤ 100
KeV.
(ELECTRONS)
COUNT RATES
(CT./SEC.)
MAGNETIC
MEASUREMENT
α
ψ
|F|
INBOUND
13 SEPT. 1961
|F| (GAMMA)
400
300
200
100
180
120
60
0
360
240
120
0
CDS DETECTOR
RESPONSE
(CT./SEC.)
CdS TOTAL
ENERGY FLUX
←50 ERGS/CM.² SEC.
STER. (10 SECOND OR
5 REVOLUTION
AVERAGE)
←Cd STE
Cd SB
30
40
50
60
70
80
GEOCENTRIC DISTANCE KM x 10³
4
5
6
7
8
9
10
11
12
Re

Figure 3

63-16

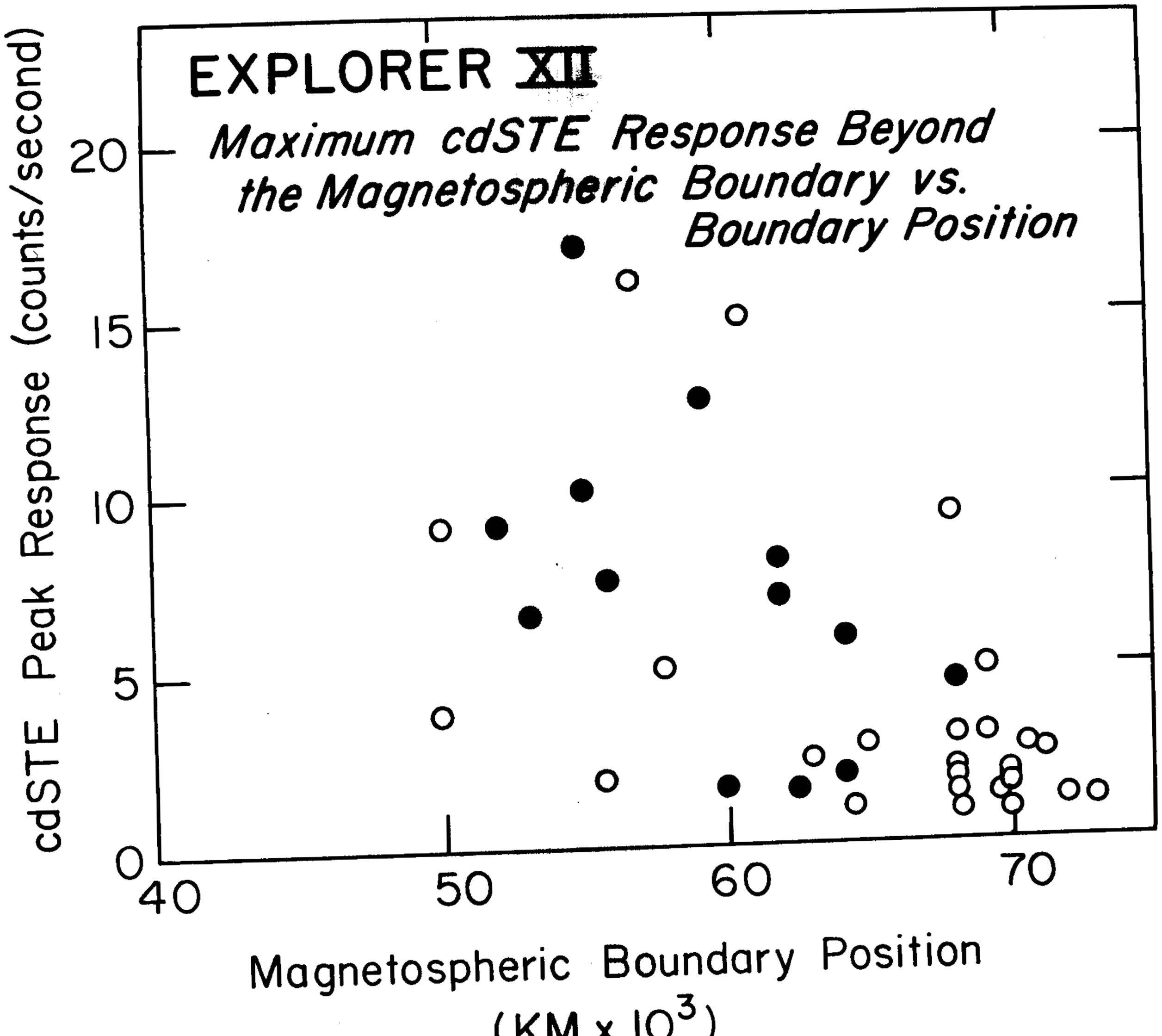


Figure 4

63-211

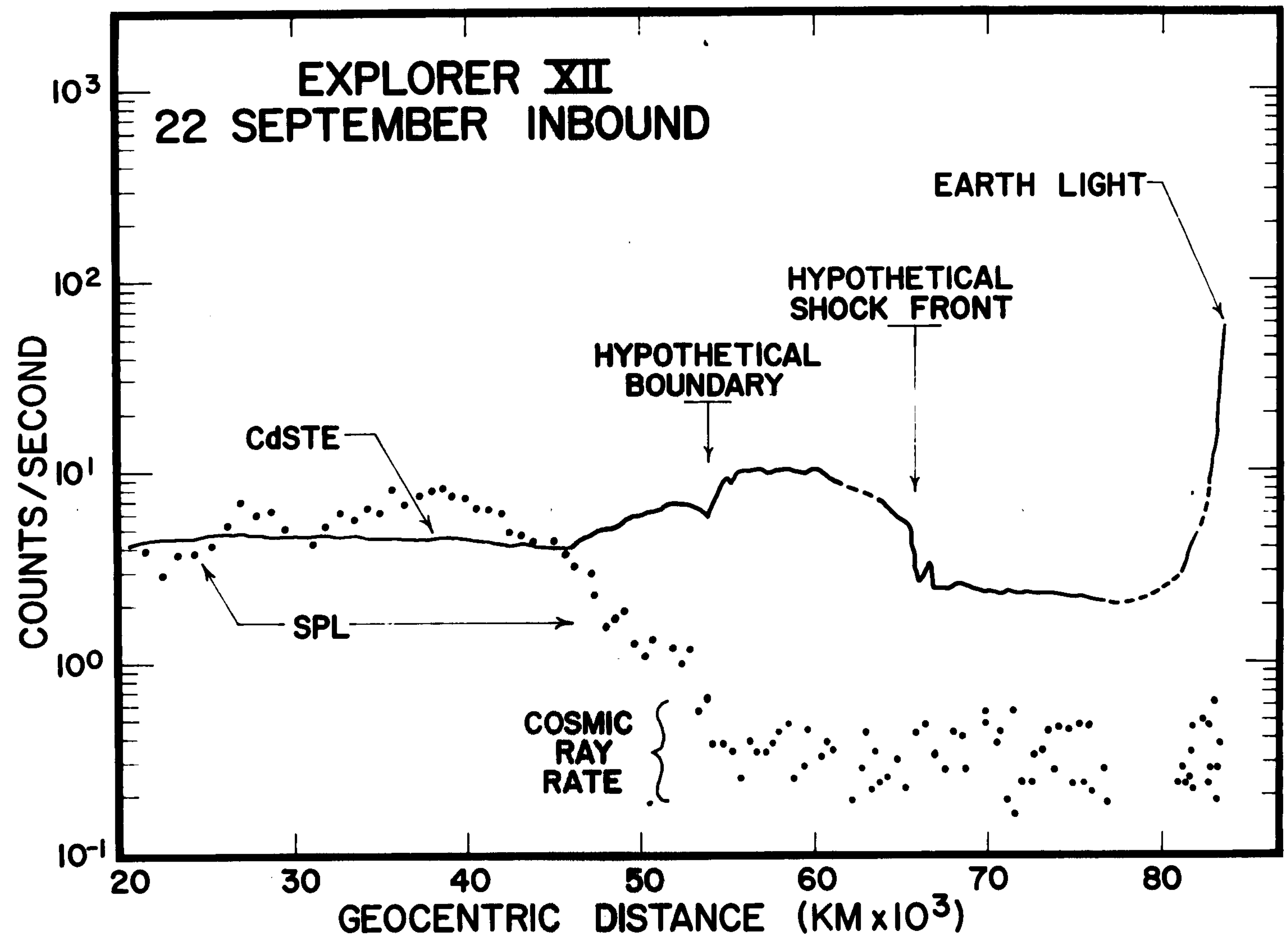


Figure 5

63-230

EXPLORER XII

RADIAL POSITION OF THE MAGNETOSPHERIC BOUNDARY AS MEASURED BY TRAPPED ELECTRONS (SPL-SPB) COMPARED WITH $D_{st}(H)$.

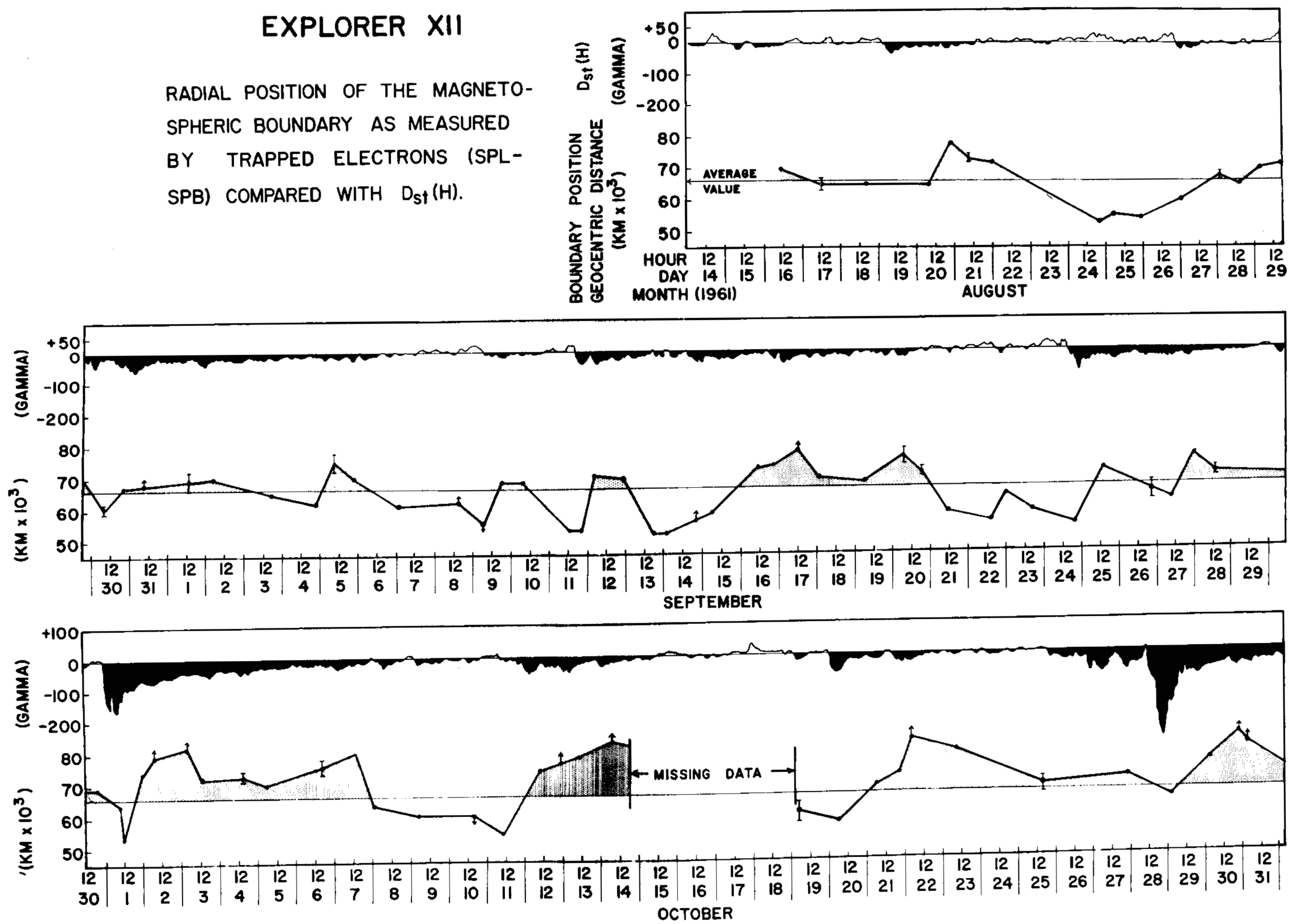
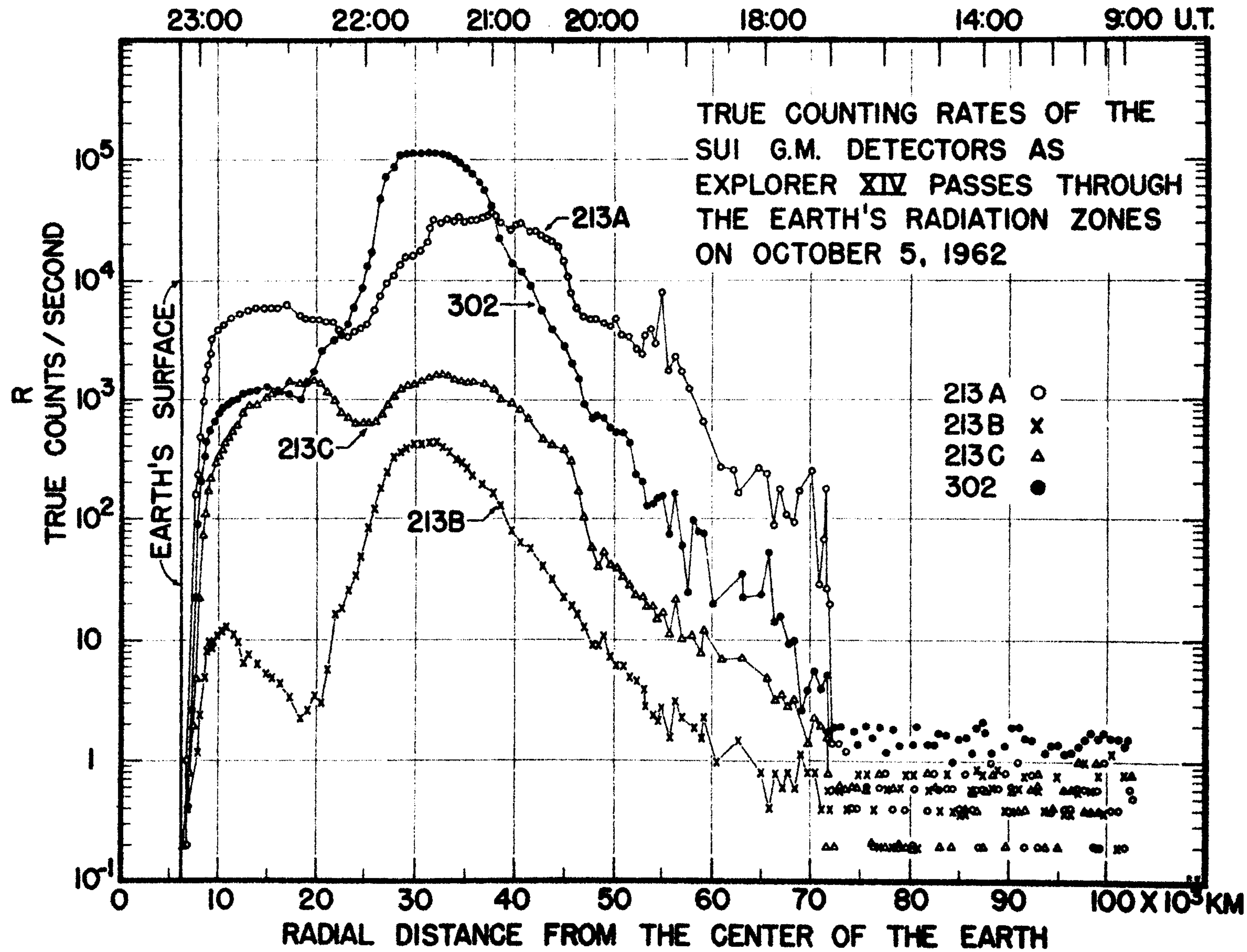


Figure 6



TRUE COUNTING RATES OF THE SUI G.M. DETECTORS AS EXPLORER XIV PASSES THROUGH THE EARTH'S RADIATION ZONES ON OCTOBER 5, 1962
23:00
22:00
21:00
20:00
18:00
14:00
9:00 U.T.
R
TRUE COUNTS / SECOND
10^5
10^4
10^3
10^2
10
1
10^{-1}
EARTH'S SURFACE
213A
302
213C
213B
213 A ○
213 B x
213 C △
302 ●
0
10
20
30
40
50
60
70
80
90
100 X 10^3 KM
RADIAL DISTANCE FROM THE CENTER OF THE EARTH

Figure 7

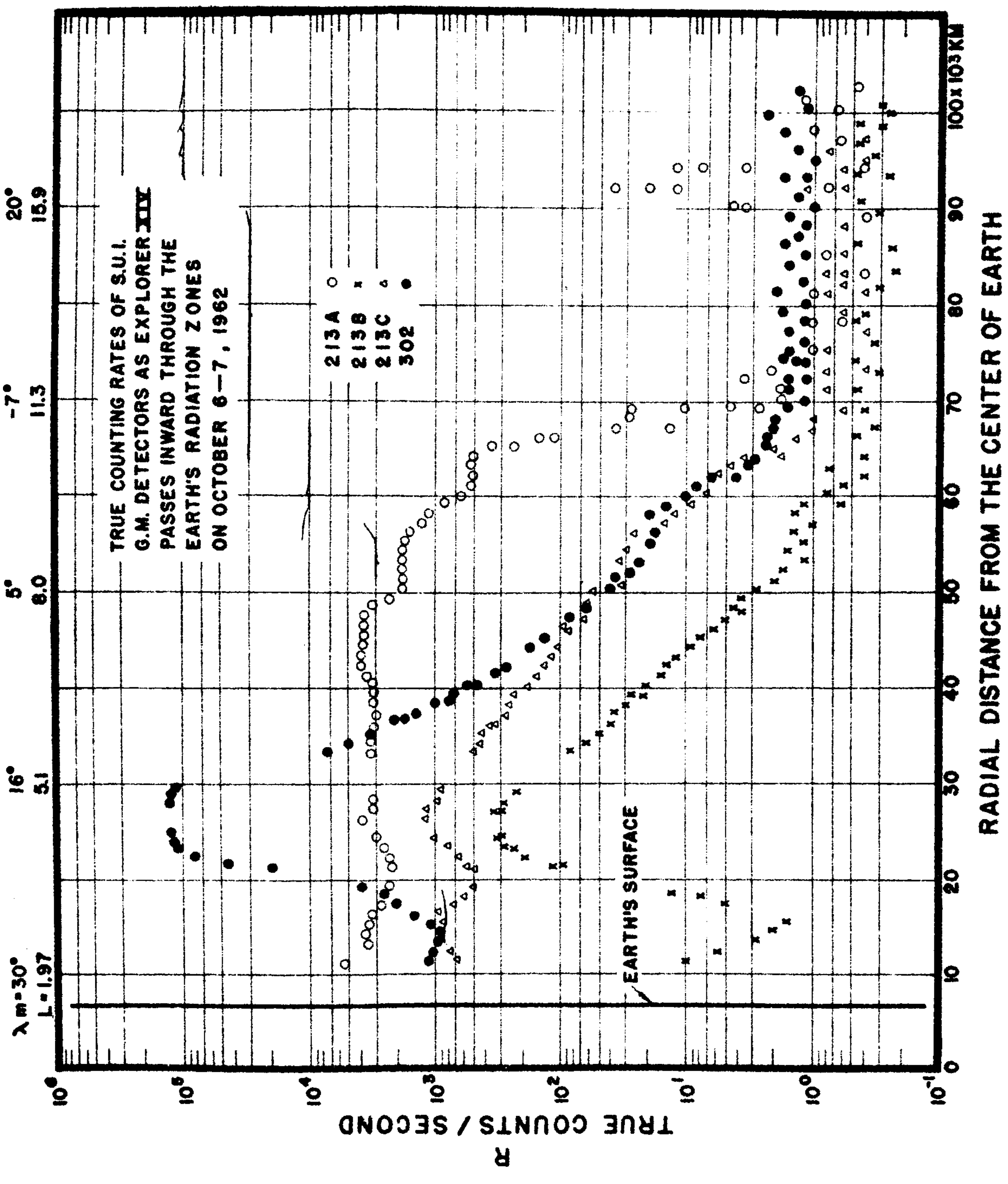

TRUE COUNTING RATES OF S.U.I.
G.M. DETECTORS AS EXPLORER XIV
PASSES INWARD THROUGH THE
EARTH'S RADIATION ZONES
ON OCTOBER 6—7, 1962
213A
213B
213C
302
EARTH'S SURFACE
λm=30°
L=1.97
16°
5.1
5°
8.0
-7°
11.3
20°
15.9
R
TRUE COUNTS / SECOND
RADIAL DISTANCE FROM THE CENTER OF EARTH
100x10³KM

Figure 8

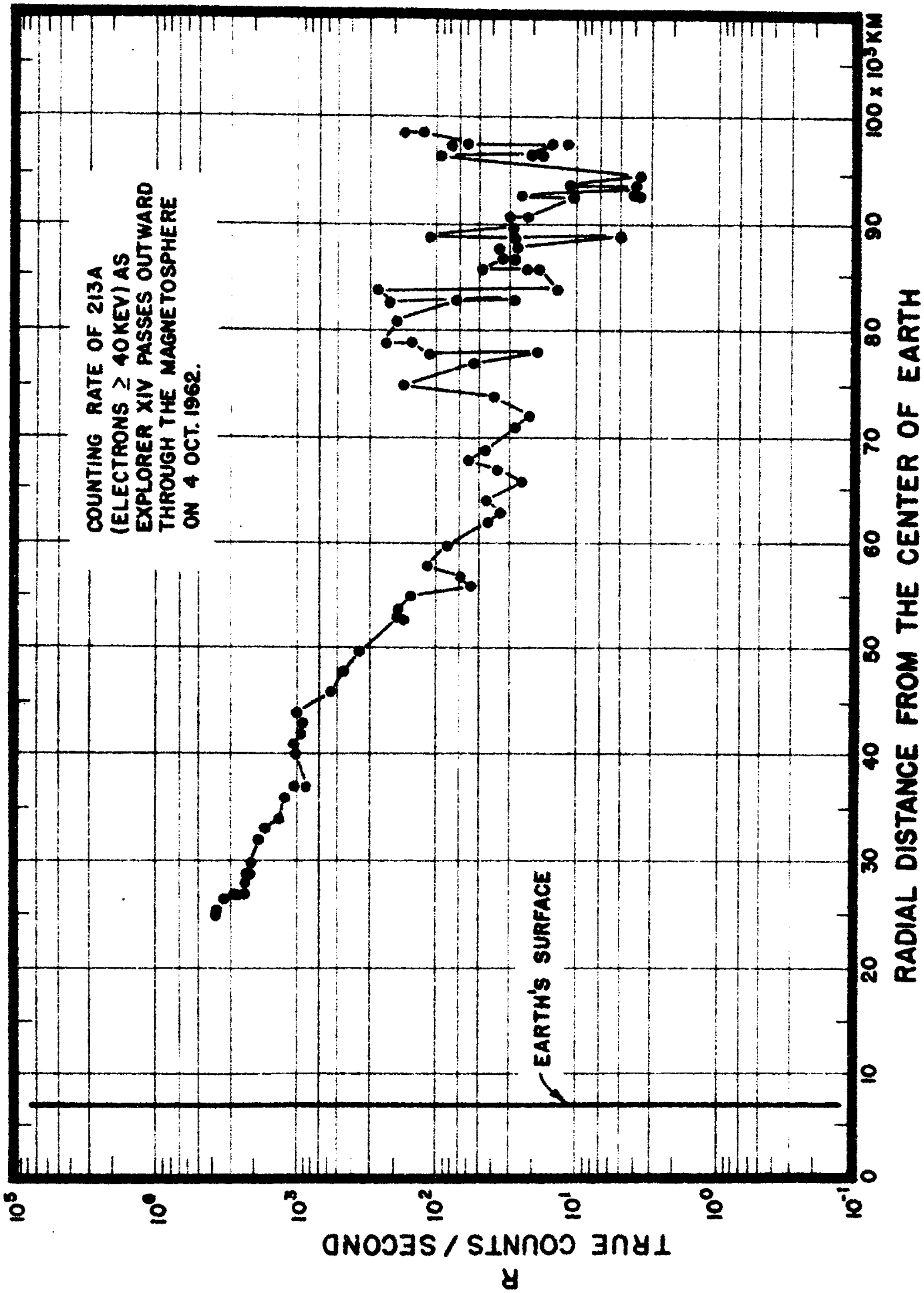

COUNTING RATE OF 213A
(ELECTRONS ≥ 40 KEV) AS
EXPLORER XIV PASSES OUTWARD
THROUGH THE MAGNETOSPHERE
ON 4 OCT. 1962.
EARTH'S SURFACE
R
TRUE COUNTS / SECOND
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0
10
20
30
40
50
60
70
80
90
100 x 10^3 KM
RADIAL DISTANCE FROM THE CENTER OF EARTH

Figure 9

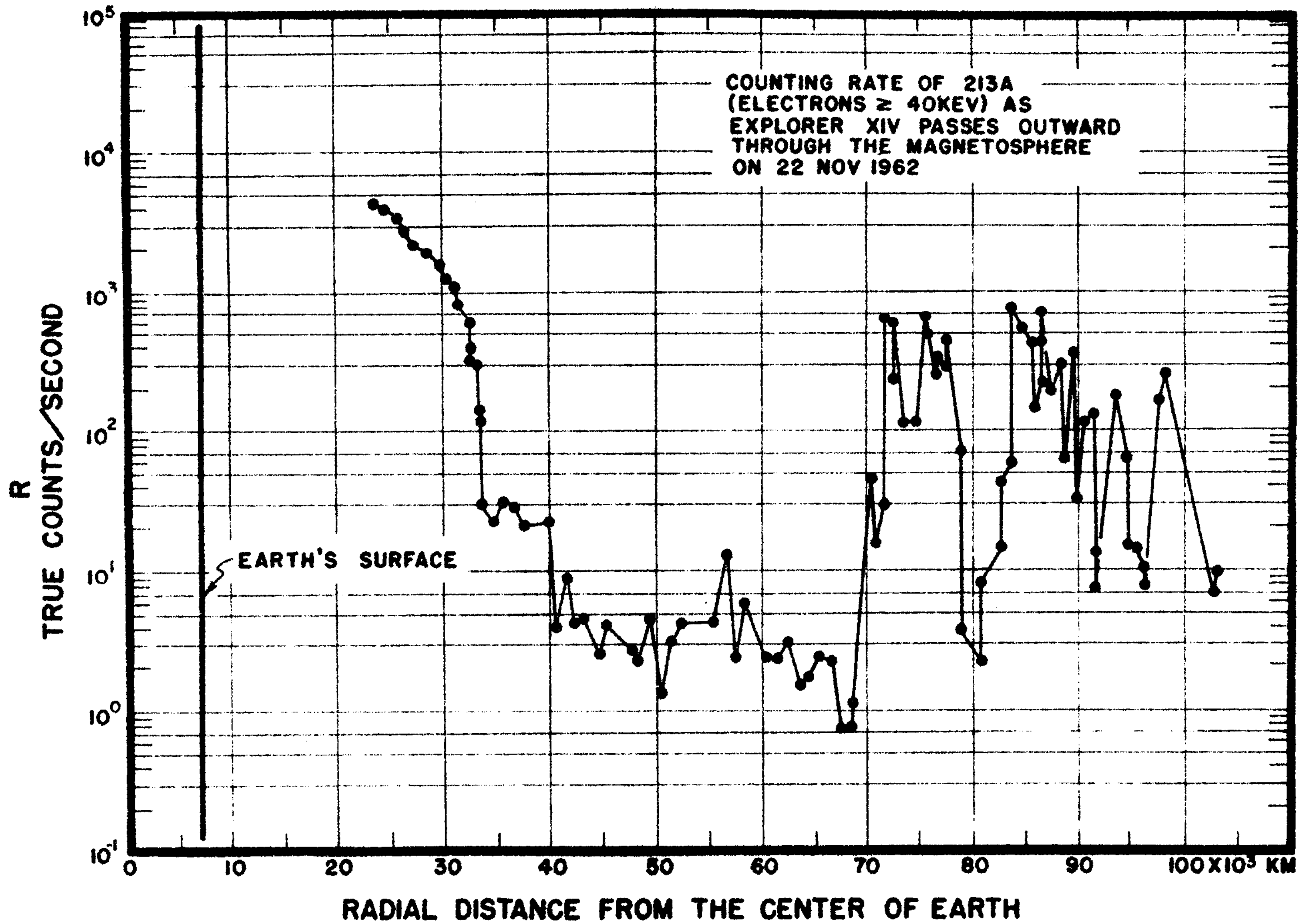
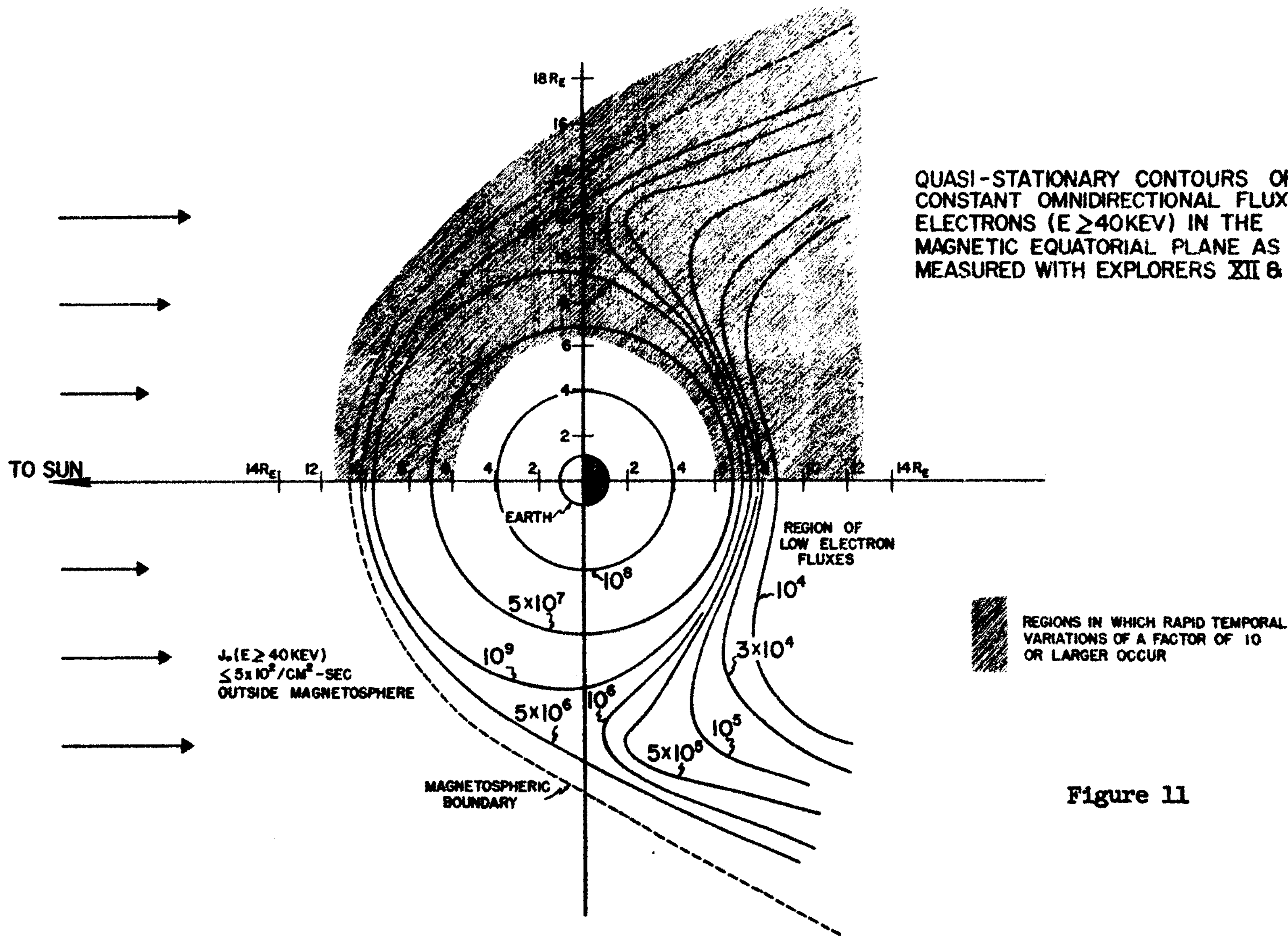

COUNTING RATE OF 213A
(ELECTRONS ≥ 40KEV) AS
EXPLORER XIV PASSES OUTWARD
THROUGH THE MAGNETOSPHERE
ON 22 NOV 1962
EARTH'S SURFACE
R
TRUE COUNTS/SECOND
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0
10
20
30
40
50
60
70
80
90
100 X 10^3 KM
RADIAL DISTANCE FROM THE CENTER OF EARTH

Figure 10



QUASI-STATIONARY CONTOURS OF CONSTANT OMNIDIRECTIONAL FLUX OF ELECTRONS ($E \geq 40 KEV$) IN THE MAGNETIC EQUATORIAL PLANE AS MEASURED WITH EXPLORERS XII & XIV

Figure 11